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EFFECT OF GROUND ON LIFT OF INFINITELY THIN AEROFOIL WITH FLAP

Introduction

The flying vehicle using the ground effect in English literature is called a Wing-In-Ground Effect (WIG) Craft and in Russia, the same vehicle usually has the name «ekranoplan». It is important for the design of such aircraft to study the effect of the ground on the aerodynamic characteristics of the wing for such vehicles. People have long used different methods to study the WIG. Among them, the numerical-analytical method (NAM) [1] is relatively high in accuracy, fast in implementation, and can reduce the storage capacity of the computer, and has shown an advantage in the research of the airfoil lift analysis in recent years. However, most studies of the effect WIG were limited to considering the aerodynamic airfoil without a flap [1, 2]. This paper will study the lift coefficient combination of a thin airfoil with a flap in close proximity to the ground. This will undoubtedly be more complicated and more comprehensive, studying the theoretical versatility of the thin-wing type, and the flap will play a very important role in the take-off and landing of the aircraft.

Models of Airfoil

It is assumed that the motions of fluid and airfoil are both two-dimensional, and the flow field is potential flow. The model in questionis shows in fig.1. The thin plate airfoil has a chord length and the inflow direction of the infinite stream has an angle of attack. The flap has a chord length and an angle of deflection. The distance above the ground is the height of the airfoil (the length of the height is the vertical distance from the tail of the flap to the ground).

Since the object of research is a thin airfoil near the ground, it is assumed that the model of the airfoil is simplified to an ellipse with a thickness close to zero. The flap and the ground are composed of a series of finite infinitesimal boundary elements according to the discrete vortex method.

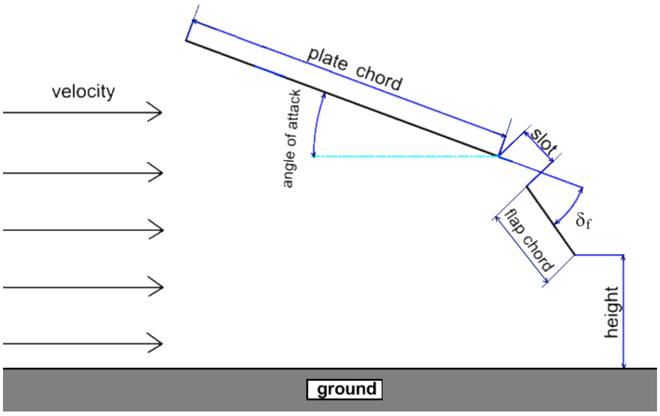

Fig. 1. Simplified diagram of research model

NAM Procedure

The paper uses the NAM method [1-3]. A feature of the NAM method in this paper is the use of boundary elements only on the flap surface and the ground.

According to the main ideas of the NAM method [1-2], the complex flow potential can be written as

$$\mathrm{W}(\zeta)=\frac{1}{2}\left[\bar{V}_{\infty}\zeta+V_{\infty}\frac{r^2}{\zeta}\right]+\sum_{\mathrm{j=1}}^{\mathrm{N_{flap}+N_{ground}}}\left\{\frac{\Gamma_{\mathrm{j}}}{2\pi i}\left[\ln\frac{\left(\zeta-\zeta_{vj}\right)\cdot\zeta}{\left(\zeta-\frac{r^2}{\bar{\zeta}_{vj}}\right)}-\right]\right\}+\frac{\Gamma_m}{2\pi i}\ln\zeta, \tag{1}$$

where V_∞ and $\bar{V}_\infty$ are the complex velocity and conjugate complex velocity of infinity flow; ζ is complex coordinate on the mapped plane; r is the radius of the circle on the mapped plane; N_{flap} and N_{ground} are numbers of boundary elements on the flap surface and the ground surface, respectively; $m=\mathrm{N_{flap}}+\mathrm{N_{ground}}+1$ is total number of control points; $i=\sqrt{-1}$ is the imaginary unit; Γ_j is the circulation of the j-vortex; ζ_{vj} and $\overline{\zeta_{vj}}$ are the coordinate and conjugate coordinate of j-vortex points; Γ_{m} represents the value of the circulation of the vortex point that is used to satisfy the Kutta condition.

In order to use eq. (1) to predict the flow, it is necessary to calculate circulations generated by point vortices. The impermeability boundary conditions are used in each control point on the model of the flap and the ground surface, and the Kutta condition is used in the control point at the trailing edge of the flap. Thus circulations are calculated by the m-variable linear system of equations

$$\begin{bmatrix} A_{1,1} & \cdots & A_{1,n+1} \\ \vdots & \ddots & \vdots \\ A_{m,1} & \cdots & A_{m,m} \end{bmatrix}\begin{bmatrix} \Gamma_1 \\ \vdots \\ \Gamma_m \end{bmatrix}=\begin{bmatrix} R_1 \\ \vdots \\ R_m \end{bmatrix}, \tag{2}$$

where $A_{i,j}$ is the influence of the j-th vortex point on the normal velocity of the i-th control point; R_i is the influence of the analytical part (the first term of the complex potential, see eq. (1)) on the normal velocity of the i-th control point.

Solving eq. (2), the circulation of each vortex point is obtained. The velocity of an arbitrary point on the physical plane is obtained by the following equation:

$$u = \mathrm{Re}\left[\frac{dW(\zeta)}{d\zeta}\cdot\frac{d\zeta}{dz}\right], \qquad v = -\mathrm{Im}\left[\frac{dW(\zeta)}{d\zeta}\cdot\frac{d\zeta}{dz}\right], \tag{3}$$

where u,v are velocities along X-axis and Y-axis, respectively.

It is necessary to determine the number of boundary elements and the length of the ground surface to ensure sufficient calculation accuracy.

Results

The calculations showed that to achieve high accuracy 2000 elements (Fig. 2) and relative length of the ground equal 40 (Fig. 3) are enough. In the future, all the calculations in this article are performed for these selected numbers. In Fig. 4 and Fig. 5 show the streamlines for the physical plane and for the plane of the auxiliary variable (mapped plane) for flow near the ground.

According to Kutta-Zhukovsky theorem, the lift coefficient can be expressed as by the following formula

$$\mathrm{c}_l = -\frac{\rho V_\infty \Gamma}{\frac{\rho V_\infty{}^2}{2}\cdot c} = -\frac{2\Gamma}{V_\infty c}, \tag{4}$$

where ρ is the density of approaching flow; c is the sum of the chord of plate and chord of the flap; Γ is the total circulation around the airfoil.

The total circulation around the airfoil could be calculated by integrating every point's velocity along a curve enclosing airfoil in anticlockwise direction or by summing values of all the circulations of the vortices using Stokes's theorem

$$\Gamma = \oint\left(udx + vdy\right) = \sum_{j=1}^{+1}\Gamma_j\ , \tag{5}$$

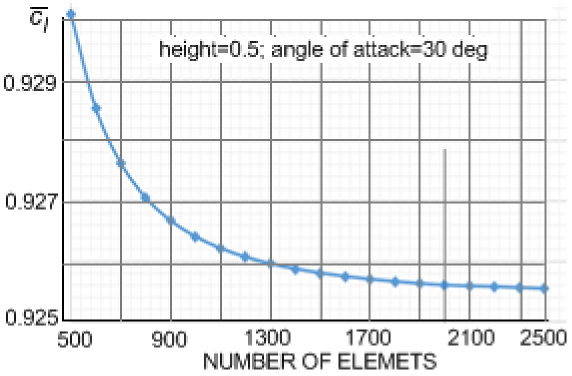

Fig. 2. Influence number of elements

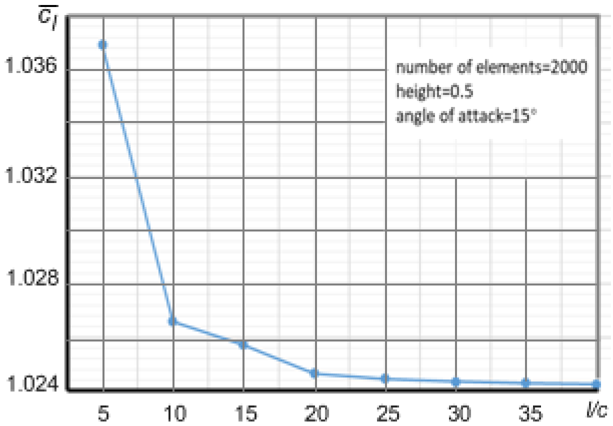

Fig. 3. Influence length of the ground

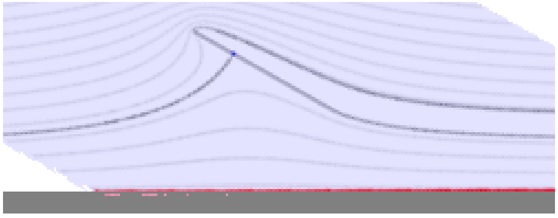

Fig. 4. Streamlines on physical plane

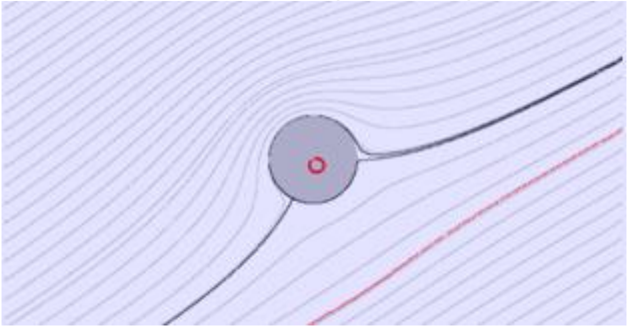

Fig. 5. Streamlines on mapped plane

Fig. 6 shows the change in lift coefficient depending on the flap deflection angle for unlimited flow. It can be concluded from Fig. 6 that the lift coefficient increases with the increasing of the deflection angle of the flap in an almost linear proportion that is consistent with the results [1].

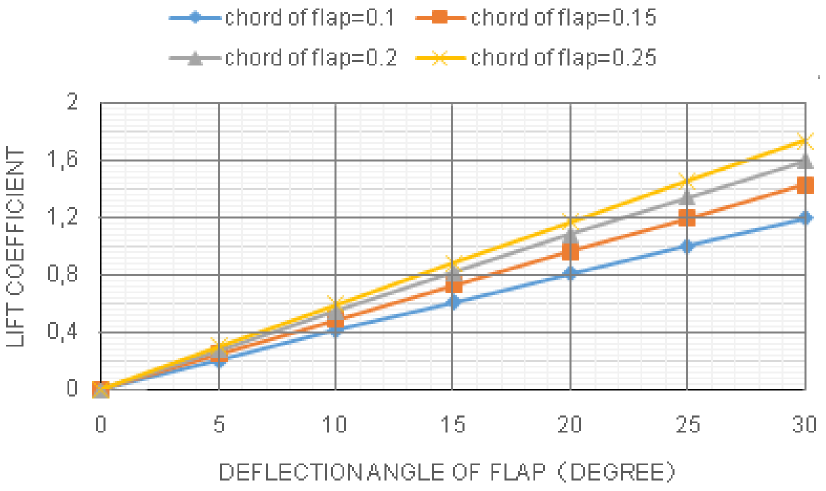

Fig. 6. Lift coefficient vs deflection angle of flap for case without ground

Fig. 7 shows the change in lift coefficient depending on the angle of attack and on the height of the plate with the flap. What can be seen from the data in fig. 7, it can be found that the relative lift coefficient $\left(\bar{c}_l = c_{l|h} / c_{l|h=\infty}\right)$ decreases with the increase of the angle of attack at the same height above the ground. At the same angle of attack (when smaller than 15°), the relative lift coefficient decreases with increasing height, and the smaller the angle of attack, the faster the rate of decrease. When the angle of attack is larger than 15°, the relative lift coefficient will first decrease to below 1 and then gradually increase to 1. Fig. 7 shows the green zone of the positive effect and the white zone of the negative effect.

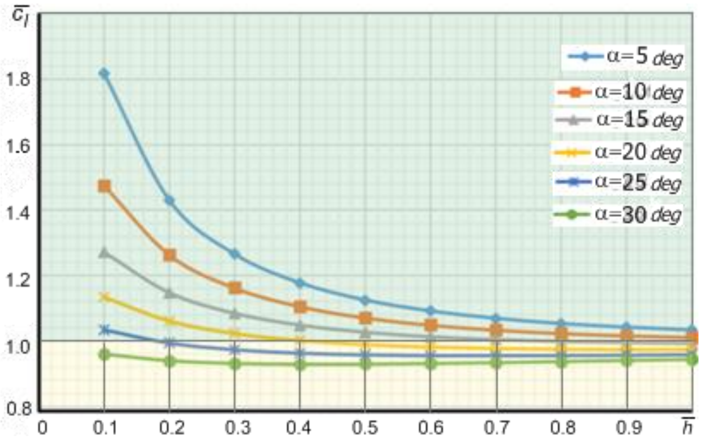

Fig. 7. Influence of height and different angle of attack

Fig. 8, 9 and 10 show the change in lift coefficient depending on the angle of attack, the height and deflection angle of the flap. The calculations were performed with the number of boundary elements on the surface of the flap $n_{\text{flap}}=200$ and on the surface of the ground $n_{\text{ground}}=2000$.

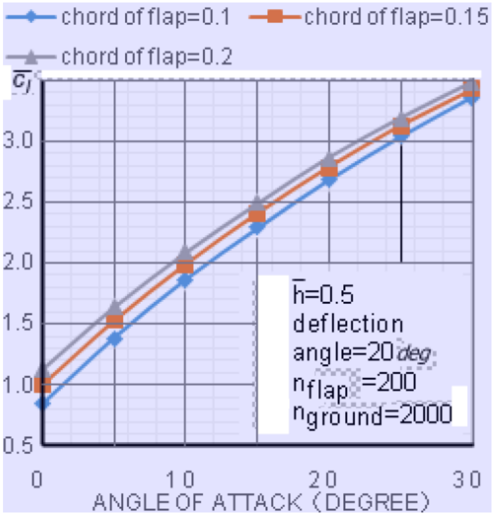

Fig. 8. Lift coefficient vs angle of attack

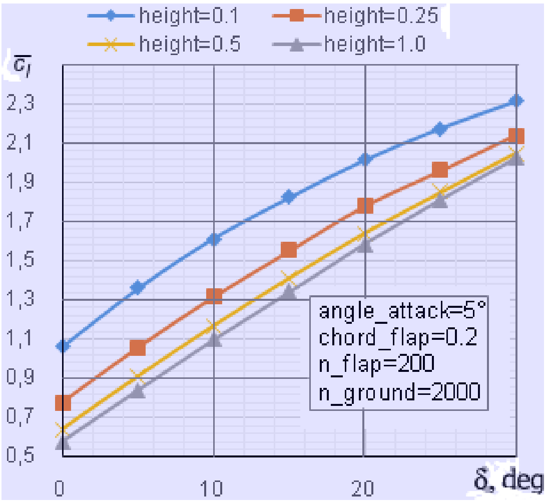

Fig. 9. Lift coefficient vs deflection angle of the flap and height

Conclusion

– The numerical-analytical method allows quickly and with high accuracy to calculate the flow near a thin airfoil with a flap near the ground.

– A decrease in height to the ground, an increase in the chord of the flap and an increase in the deflection angle of the flap lead to an increase in lift.

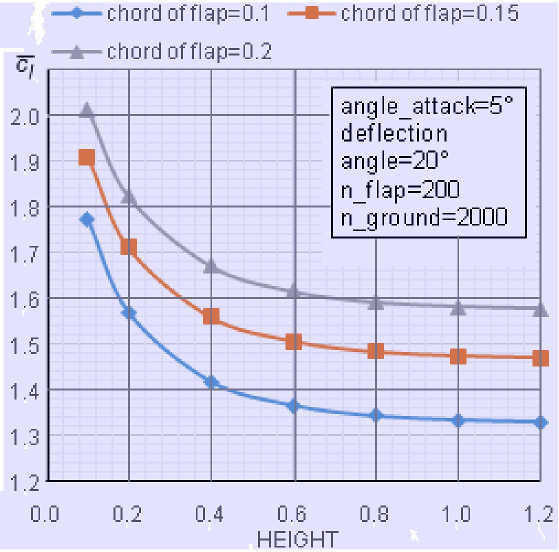

Fig. 10. Lift coefficient vs height and chord of the flap

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